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Analysis of dynamic characteristics of boring tool holder

P.Sam Paul[a1*],G. Lawrence[a2] ,Rohit Kumar Yadav[b1], Nair Vineeth Mohankrishnan[b2], Nishant Nair[b3], X. Ajay Vasanth[c1],

a1 Assistant Professor (S.G),School of Mechanical Sciences, Karunya University, Coimbatore, 641114, Tamil Nadu; India*
a2 *Assistant Professor,School of Mechanical Sciences, Karunya University, Coimbatore, 641114, Tamil Nadu; India*
b1 Student, B.Tech Mechanical, School of Mechanical Sciences, Karunya University, Coimbatore, 641114, Tamil Nadu; India
b2 Student, B.Tech Mechanical, School of Mechanical Sciences, Karunya University, Coimbatore, 641114, Tamil Nadu; India
b3 Student, B.Tech Mechanical, School of Mechanical Sciences, Karunya University, Coimbatore, 641114, Tamil Nadu; India
c1 *Assistant Professor,School of Mechanical Sciences, Karunya University, Coimbatore, 641114, Tamil Nadu; India*

Abstract

Machining is a complex process in which many variables can detrimental the desired results. Among them, tool vibration is the most critical phenomenon which affects the life of the cutting tool, quality of the components machined and functional behaviour of the machined tools. This familiar phenomenon is recognized in many operations including boring, milling and drilling. The causing factors are related to the machine tool itself, tool clamping, length and diameter of the tool holder and the cutting data to be used. One way to avoid vibration problem during boring process is the location of boring tool holder in the relevant position for increasing the precision of the machining process. The present investigation aims at determining the optimum position of tool shank overhang for a boring tool holder S25T PCLNR/L12 and also to study the effect of damping force on tool vibration using Analytical, computational and experimental methods.

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Keywords: Tool Holder; Boring; Harmonic analysis; Deflection;Modal Analysis ; Natural Frequency; Damping ratio

1. Introduction

Technology is advancing; demand of the hour is also increasing. Now-a-days, the challenge of modern machining industries are mainly focused on the achievement of high quality, dimensional accuracy of work piece, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and

Corresponding Author: Tel: +91-9443496082, Fax:0422-2615615; e-mail: psam_paul@rediffmail.com

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increase the performance of the product with reduced environmental impact. In the turning operation, vibration is a frequent problem, which leads to poor surface finish, cutting tool damage and production of irritating noise. Excessive tool vibrations during machining will increase the tool wear and cause poor surface finish. As a result of tool vibration, severe acoustic noise in the working environment frequently occurs and tool life gets affected. In all cutting operations like turning, boring and milling, tool vibration develop as a result of the dynamic interaction between the structures and the cutting process. The wavy surface left by vibrations is removed in the next pass in a dynamic cutting process. The vibrating tool and the wavy surface result in modulated chip thickness, which causes periodically varying cutting forces to excite the machine and work piece structures. Under certain conditions, the amplitude of the vibrations grows continuously, resulting in instability, i.e. self-excited chatter vibrations.

Today the standard procedure to avoid vibration during machining is by careful planning of the cutting parameters and the location of tool holder and work piece. The methods are usually based on experience and trial and error to obtain suitable cutting data and location for each cutting operation involved in machining a product. Tool vibration is influenced by many sources, such as machine structure, tool type, and work material, location of work piece & tool holder. The fundamental mechanism of tool vibration has been investigated, explored and analyzed. Jon Robert Pratt (1997) explored the dynamics and control of machine-tool vibrations with particular attention to boring-bar chatter. The focus was to devise a unique manufacturing research platform known as the Smart Tool. Ivana Kovačić (1998) presented the affect of the critical cutting speed (threshold of chatter) on the tool which makes it oscillates with the constant amplitude for the cutting process. The results showed that the oscillatory motion of the tool disappears when the cutting speed is higher than the critical one and when the cutting speed is smaller than the critical value, the self-excited vibration occurs. Agapiou et al. (2005) investigated the use of optimal materials and geometries which often is the preferred approach to enhance the stability of boring bars and cantilever tools. It resulted in the light weight design of the overhang segment at the end of the tool, which holds the tool bit or insert to increase the natural frequency of the cutting point. Tatiana Smirnova, (2008) investigated that the”3-D” finite element model of the system resulted in fairly accurate estimates of the boring bar’s fundamental bending mode Eigen frequencies which predict the control paths accurately. Nasser proposed that the filling process of the overhang boring bars with particulate composites is an optimum way to control self excited vibrations of boring machines by controlling its peak amplitudes at the lowest levels within a wide frequency range. Edmund Isakov (2006) proposed a paper which deals with the study of boring bar material analysis, procedural methods and dimensional analysis of boring bar. He proposed that the high damping materials like carbide derivatives proved to be highly effective and efficient unlike conventional Aluminium Alloys due to the dynamic factors. The results also showed that the L/D ratio is directly proportional to the amount of vibration. From the literature, it was understood that the tool vibration causes lot of problems and a major problem that arise is that it causes reduction in tool life. The aim of this investigation is to analyze the turning tool holder using Computational, Analytical and Experimental methods for different overhang tool shank position which results in reduction of tool vibration.

2. Tool holder

The tool holder S25T PCLNR/L12 used in the investigation was an alloy steel tool having specification of diameter 25mm and length of 300 mm. The geometry of the tool holder is as shown in Figure 1.

Figure 1 Geometry of tool holder S25T PCLNR/L12

The tool holder consists of parts namely Tool Shank, Insert, and Sim. The materials and properties of the tool holder are specified in Table 1.

Table 1. Material properties

Material	Property	Density Y Kg/m ^{3}	Young's modulus N/m^2	Poisson's Ratio
Tool shank	Alloy steel	7850	2.09E+11	0.3
Insert	Tungsten carbide	15800	5.50E+11	0.28
Sim	Steel	7850	2.09E+11	0.29

3. Computational Analysis

Tool holder along with the insert and sim was modeled and analyzed using Ansys software to determine the dynamic characteristics.

3.1. Geometric Model

The geometry of the tool holder along with the insert and sim was modeled in Ansys software as shown in Figure 2. The element 8 node solid 185 was chosen for the analysis.

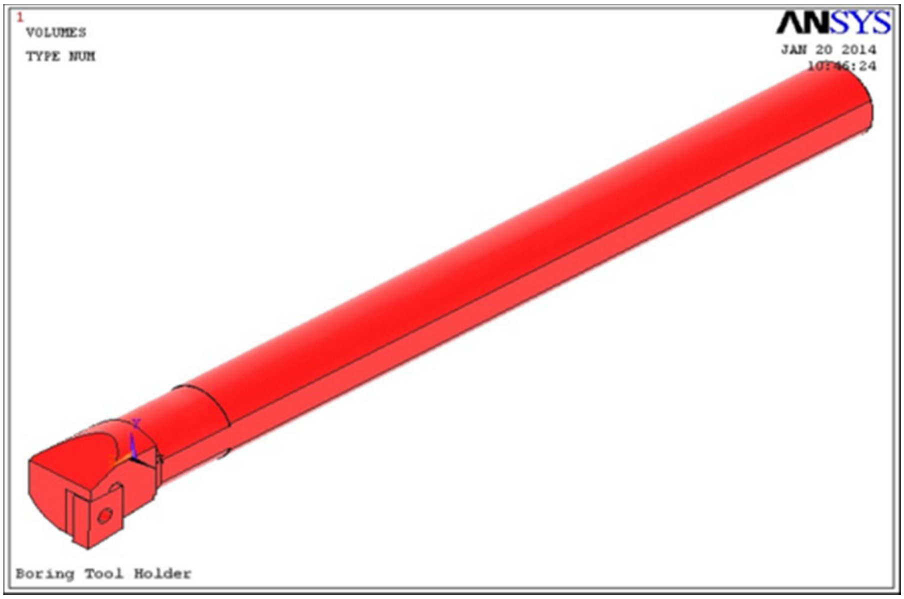

Figure 2. Tool Holder PSBNR 2525 M12

3.2. Grid Independence Study

The number of elements to be chosen for idealization is related to the accuracy desired. Although an increase in the number of elements generally means more accurate results, for any given problem there will be certain number of elements beyond which the accuracy cannot be improved by significant amount. This behavior was done using Grid Independent Study. The Grid Independent Study was carried out so as to obtain the limit where the deflection becomes constant. The number of elements was increased gradually and at a particular limit the deflection was found to be constant. As shown in Figure 3, the deflection does not change beyond 0.054 mm and the number of elements was found to be 202534 at 0.7 edge length.

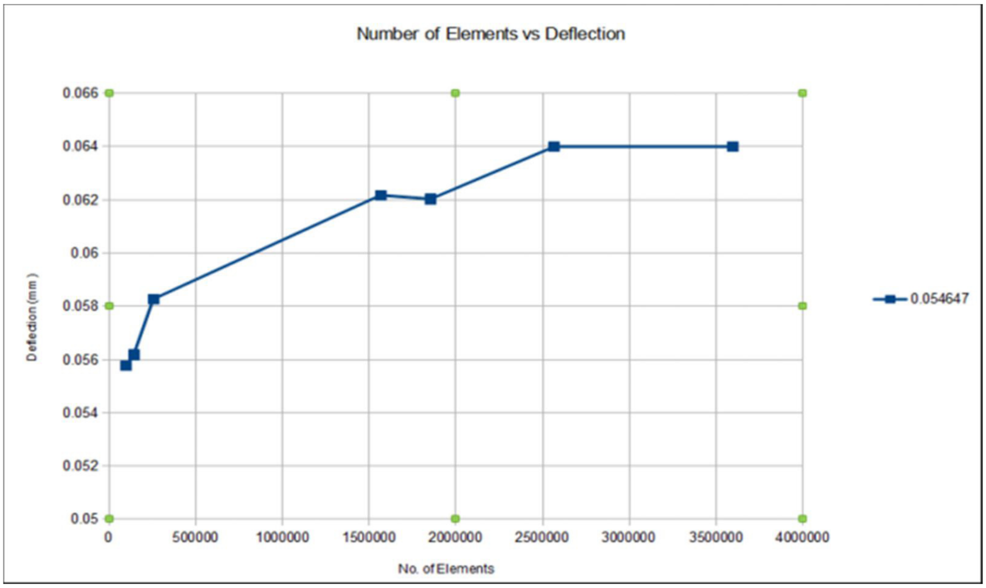

Figure 3 Grid Independence Study

3.3. Static Analysis

The static analysis was performed using ANSYS software to obtain deflection values for different overhanging positions. Solid element of type 8 node Solid 185 was used in this study. Considering the tool holder as a cantilever beam, all degree of freedom was fixed for different overhanging positions. Four different overhangs (100 mm, 150 mm, 200 mm, and 250 mm) were used to analyze the deflection value. The overhang was not reduced below 100mm because practically it is not possible to perform the boring operation which results in interference of tool and work piece. A point load of 500N was applied at the tip of the tool holder in vertical direction. The static analysis was performed for different overhanging positions separately and the corresponding maximum deflections are noted. Table 2 presents the different overhanging length and their deflection values. From the result, it can be seen that deflection decreases when the overhanging length decreases. Deflection is minimum when the tool holder has an overhanging length of 100 mm as presented in Figure 4.

Table 2. Tool overhang length VS deflection

Sl. No.	Overhang length (mm)	Deflection (mm)
1	100	0.054647
2	150	0.181179
3	200	0.406193
4	250	0.781851

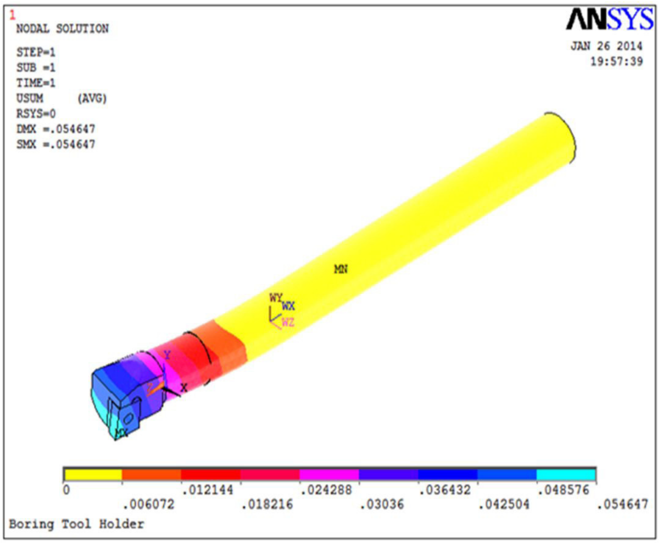

Figure 4 Deflection at 100 mm overhang

3.4. Modal analysis

Modal analysis is the field of measuring and analyzing the dynamic response of structures and fluids when excited by an input. Modal analysis is frequently utilized to abstract the modal parameters of a system, including natural frequencies and mode shapes. Modal analysis is the fundamental response analysis and has therefore gained more attentions. Modal analysis was performed and the maximum natural frequency obtained at 100 mm overhang was 303 Hz.

Table 3. Modal analysis for 100mm overhang

Set	Time/frequency
1	56.353
2	57.610
3	262.66
4	291.31
5	303.42

3.5. Harmonic analysis

Harmonic analysis is a branch of mathematics concerned with the representation of functions or signals as the superposition of basic waves, and the study of and generalization of the notions of Fourier series and Fourier transforms (i.e. an extended form of Fourier analysis). Fourier analysis: analysis of a periodic function into a sum of simple sinusoidal components. Any sustained cyclic load will produce a sustained cyclic response in a structural system. Harmonic response analysis gives the ability to predict the sustained dynamic behaviour of structures, thus enabling to verify whether or not the designs will successfully overcome resonance, fatigue, and other harmful effects of forced vibrations. Harmonic response analysis is a technique used to determine the steady-state response of a linear structure to loads that vary sinusoidally with time. In this study, a load of 500 N is applied on the tip of the tool holder and the value of forced frequency is obtained. The sinusoidal curve thus obtained is used to calculate the damping ratio using the Half–power bandwidth method as explained in Figure. Damping ratio values for boring tool holder with (damper at 85 mm) and without damper is tabulated in table 4. Harmonic analysis for boring tool (at 250 mm overhang) with and without damper is presented in Figure 5.

Table 4. Damping ratios without and with damper at 85mm

Sl. no	Overhang length (mm)	Damping ratio (with damper)	Damping ratio (without damper)
1	100	0.0333	0.0333
2	150	0.0666	0.01818
3	200	0.0625	0.0161
4	250	0.125	0.0238

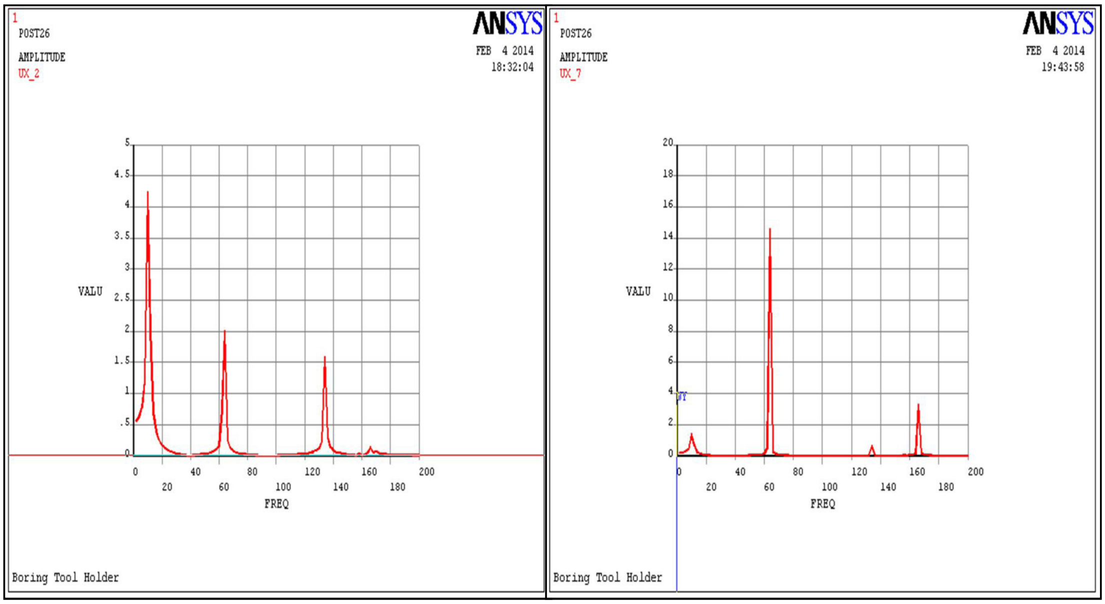

Figure 5 Harmonic analysis at 250mm overhang a) with damper b) without damper

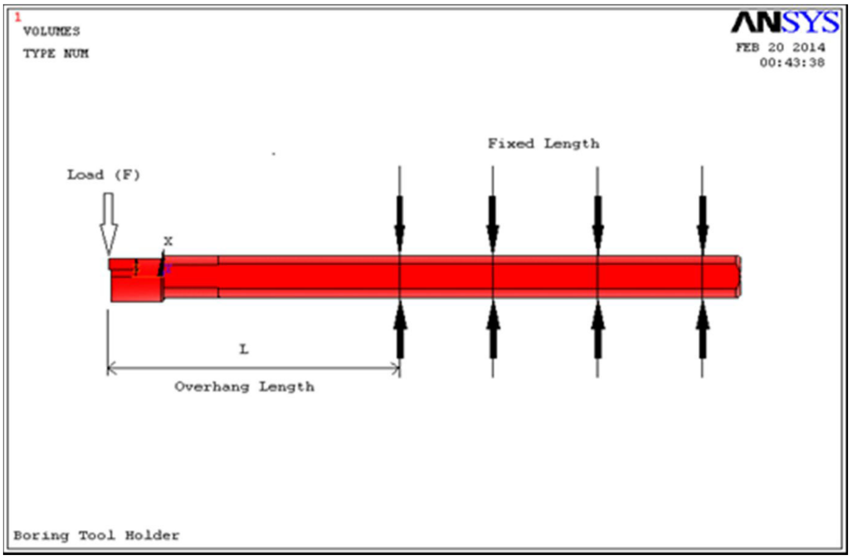

Figure 6 Deflection of a cantilever beam

3.6. Theoretical Analysis

Deflection at 100mm overhang length during the static analysis was verified using the formula;

$$\delta = \frac{P \cdot L_e^3}{3 \cdot E \cdot I}$$

$$
\begin{aligned}
where\ \delta &= deflection\ (mm)\\
P &= load\ (N)\\
E &= young's\ \text{mod}ulus\ (N/mm^2)\\
I &= moment\ of\ inertia\ (mm^4)\\
L_e &= overhang\ length\ (mm)
\end{aligned}
$$

$$Moment\ of\ Inertia, I = \frac{3.14 \cdot 25^4}{64}$$

$$I = 0.042 in^4$$

$$I = 17481.7199 mm^4$$

$$Deflection, \delta = \frac{112.4 \cdot 4^3}{3 \cdot 30 \cdot 10^6 \cdot 0.042}$$

$$\delta = 2 \cdot 10^{-3} in = 0.05 mm$$

4. Experimental analysis using FFT analyzer

Fast Fourier Transform (FFT) analyzer receives analog voltage signals (representing displacement, velocity, acceleration, strain, or force) from a signal conditioning amplifier, filter, and digitizer for computations. The analyzed signals can be used to find the natural frequencies, damping ratios, and mode shapes either in numerical or graphical form. The experimental setup is shown in Fig. 7 (a).

FFT analysis was performed on the boring tool holder S25T PCLNR/L12 using the impact hammer test. The graph was obtained and the natural frequency was found to be 281 Hz as in Fig. 7 (b).

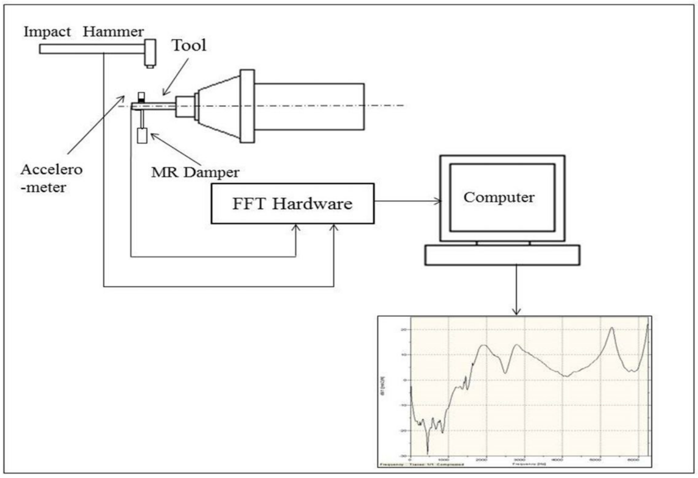

Figure7 (a)Experimental setup

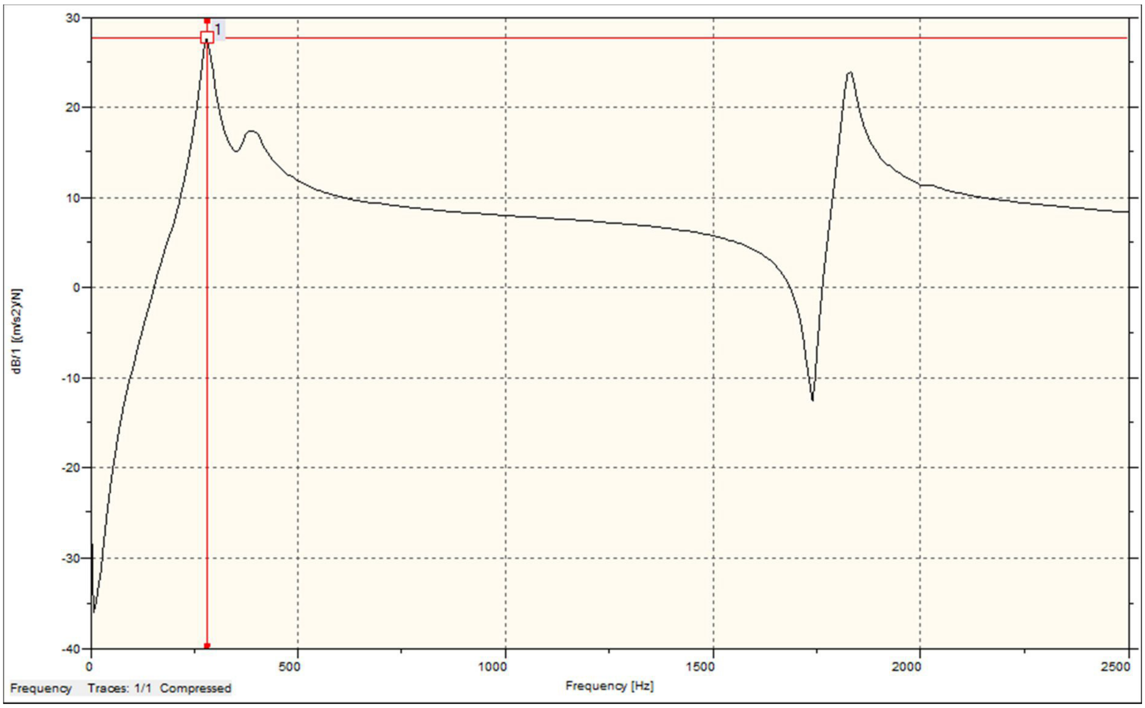

Figure7 (b) Natural Frequency curve obtained using Impact Hammer Test

5. Results and discussion

Tool Holder was positioned in different overhang 100 mm, 80 mm, 60 mm and 55 mm respectively. Finite Element Analysis of the Tool shank was performed using ANSYS software. Based on computational method, deflection obtained for different overhang positions and it is represented in Fig. 8. Comparison of theoretical, experimental and computational results is presented in the Table 5.

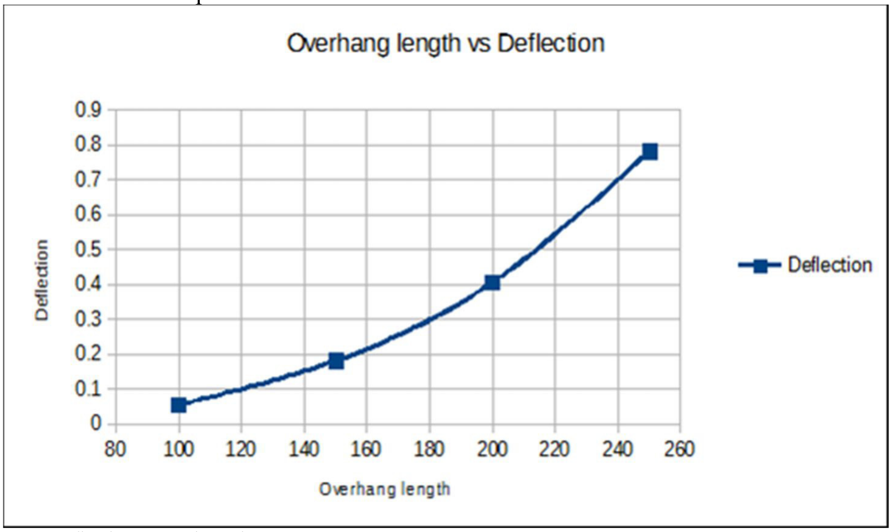

Figure8 Deflection vs. tool overhang

Table 5. Comparison of the results

100 mm overhang			
Method	Computational	Experimental	Theoretical
Deflection (mm)	0.054647	_______	0.05
Natural frequency (Hz) (5th mode)	303.42	281	_______

From the analysis it was observed that the deflection increases and frequency decreases with increase in tool overhang. Tool with 100 mm overhang length was considered to be the optimum, since it has minimum tool deflection and also it satisfies experimental criteria. Based on the computational analysis, it was observed that maximum deflection and frequency for tool overhang with 100 mm overhang was found to be 0.054647mm and 303.42 Hz respectively. Based on the theoretical, it was observed that the maximum deflection for 100mm overhang position was found to be 0.05mm. Using Impact Hammer test, it was found that the natural frequency of the tool with 100mm overhang length was 281 Hz. Since the computational results corresponds well with the theoretical and experimental data, it is inferred that for Widax tool holder of S25T PCLNR/L12 specification, an overhanging length of 100 mm was considered to be the optimum position which leads to the reduction in tool vibration, and improvement in Quality of the finished product and tool life.

4. Conclusion

This paper has a detailed description on the effect of boring tool holder with and without damper with various overhang length on tool vibration. ANSYS software was used to study the effect of damper on tool vibration during boring operation. Tool holder with insert and sim was modelled and analyzed in ANSYS. Damping force and main cutting force are given as force constraints along with fixed boundary conditions. The results obtained from computational methods reasonably explain each other. The response showed increasing frequency and decreasing damping ratio as the amplitude decreased which prevents resonance condition and hence reduces vibration in the tool. It was observed that using damper, tool vibration has been reduced and cutting performance can be improved effectively. The boring tool's dynamic characteristics on tool vibration were different for different overhang lengths. From the analysis, it is seen that, a tool holder having overhanging length of 100mm will have less deflection. In order to avoid interference during machining, this overhanging length cannot be reduced further. As the acceleration of the cutting tool increases with the increasing of the cutting tool overhang for different cutting conditions, the vibration of cutting tool depends strongly on cutting tool overhang.

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